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Forest harvesting decisions: the economics of household forest owners in the presence of *in situ* benefits

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Abstract. Within the even-aged forestry management regime, the length of the rotation period determines the age class structure of a forest area. In many countries harvesting decisions are made by households that own forest land. This paper discusses how different type of values can be included in a model that aims to explain the household forest owners' harvesting decisions. The model suggests that the *in situ* or amenity preferences make the forest rotation problem considerably more complex than in the classical rotation models based on maximum sustainable yield or maximization of timber revenues. This extended model is able to explain several empirical findings on harvesting behavior and prices of forest land. The model and its features are compared to certain ecological views on renewable resource management.

Key words: forest economics, nonmarket values, renewable resources

Introduction

In the Nordic countries, a major part of the forest land is owned by households (or nonindustrial private forest owners). For example, in Finland these own approximately 60% of the forest land area and supply about 80% of the timber. Thus their timber-harvesting decisions determine both the economic welfare from forestry and the state of nature preservation for large geographic areas. Besides the theoretical interest in natural resource economics, such understanding is needed for example for predicting the consequences of land market liberalization, changes in forest owners' income levels, and changes in their average age.

Historically, there has been an interest in promoting households' timber-harvesting activity. A more recent aim in forest policy is to change households' forest management practices in order to promote nature preservation or biodiversity goals. In either case it is possible to cause serious problems if forest owners' decision making is inadequately understood. This problem is underlined by the fact that, in the case of forestry, markets may not give economically correct signals. This follows because nontimber or *in situ* values may not have market prices, and because time horizons in forestry are very long compared to the life cycle of an average forest owner.

This paper is focused on models that determine the rotation period for even-aged stands, since in the Nordic countries forestry is based on even-aged management with the typical cutting area being about 1–2 hectares. The analysis focuses on the economic aspects; the biological details are highly stylized. With the rotation model, it is possible to make the biological aspect as detailed as needed without making major changes in the economic aspects of the problem (see e.g. Valsta 1993). Within even-aged forestry management, the length of the rotation period determines the age class structure in a given forest and the age of the oldest trees. Thus the length of the rotation period determines the living conditions of various species living in the forest environment.

Timber harvesting is a solution to a decision-making problem. We study how such a problem can be formulated and what aspects may determine the length of the rotation period. Interesting issues include how different values can be included in the decision-making model and how they change the harvesting decision and, for example, the quantities of timber supplied and the price of timber. From the point of view of nature preservation, an important question is how much should forest owners be compensated if the aim is to maintain their welfare level when their forests are included in nature conservation programs.

This paper studies natural resource utilization from the point of view of economics. An ecology textbook by Begon et al. (1996, p. 664) takes the view that biologists can take three different attitudes toward natural resource management problems. According to the first, ecological interactions are too complex for ecologists to make pronouncements of any kind. The second view holds that ecologists should concentrate exclusively on ecology and give recommendations designed to satisfy purely ecological criteria. According to the third view, ecologists should make ecological assessments that are as accurate as possible, taking into account that the ecological interactions they address include humans as one of the interacting species and that humans are subject to social and economic forces. This paper is in line with the third view, which Begon et al. (1996) also find as the only sensible alternative.

The paper is organized as follows. The next section explains some classical views on forest harvesting and rotation problems. Then we introduce a more general approach and analyse its implications and differences vis-à-vis the classical approaches.

Some classical views on forest-harvesting decisions

Perhaps the most traditional approach in forestry practices is the concept of Maximum Sustainable Yield (MSY). Recall that a similar view has been dominant in the case of fisheries (Clark 1990; Begon et al. 1996, p. 653). In

forestry, the intuition behind this approach is that the growth rate of trees is low in cubic meters, both when the trees are young and old. Thus applying a very short or long rotation period does not utilize the most efficient biological growing capacity. This leads to the idea that a stand should be harvested in order to maximize the annual average yield, i.e. $q(s)/s$, where $q(s)$ gives the stand biomass q as a function of its age s. Maximization of $q(s)/s$ implies that the stand is being cut when

$$q(s)/s = q'(s), \tag{1}$$

meaning that at the optimal cutting moment the average annual growth equals the growth rate of the biomass or the 'growth during the last growing season'. If the MSY concept is applied to maximize biomass production, the rotation period can be surprisingly short. According to a recent study, it may lead to rotation periods that vary between 40 and 60 years in the cases of *Picea abies*, *Pinus sylvestris* and *Betula* sp. (Valsta 1997). These rotations are short compared to actual rotations, which vary between 70 and 110 years.

In the normative sense, the approach takes a very restrictive view of human objectives since it suggests that forest owners should maximize the production of biomass. No other economic activity aims to maximize physical output. Biomass maximization also neglects that the market price of timber from old trees may be much higher than the price of timber from young trees.

From the point of view of economics, the assumption that decision making is rational implies that a normative model should obtain empirical support when testing its hypothesis. The MSY rule is highly problematic as an empirical description of how household forest owners behave. The model hypothesizes that biological factors alone determine the forest-harvesting decision. However, numerous empirical studies show that timber supply decisions are related, for example, to the price of timber (Binkley 1981; Dennis 1990; Kuuluvainen and Salo 1991). Moreover, the approach does not generate predictions of the price of forest land.

A model called 'forest rent', or net sustainable yield, takes into account timber prices and the costs of planting a new stand. The aim is to maximize the annual economic net yield over a rotation period, i.e. $[px(s) - w]/s$, where p is timber price, w is planting costs and $x(s)$ gives the commercial cubic meters of timber as a function of stand age. Maximization requires that

$$px'(s) - [px(s) - w]/s = 0. \tag{2}$$

Thus, according to this rule, a stand is cut when the increase in stand value equals the average annual growth in stand net value. The rotation period defined by Equation (2) may be considerably different from the MSY rotation. This follows because of the economic parameters and especially because biomass growth is replaced by commercial cubic meters of timber.

Although this approach uses some economic parameters, the aim of maximizing the average annual net economic yield reflects a zero rate of interest. Thus, as a normative rule, the model is valid only if forest owners can borrow and lend money at a zero rate of interest. This is possible only in highly exceptional circumstances. Another problem with this model is that, like the concept of maximum sustainable yield, it does not generate a sensible hypothesis for the value of forest land. If we sum the net benefits over an infinite horizon rotation program, the model suggests that the value of forest land is infinite, which is in contradiction with any empirical data on land markets.

The traditional economic approach to forestry decisions is the Faustmann (1849) rotation model. This simply adds the rate of interest to the model of forest rent. The Faustmann model specifies the value of bare forest land or the profits of the owner of bare forest land as

$$V = \sum_{i=1}^{\infty} [px(s)e^{-rs} - w]e^{-rsi}, \tag{3}$$

where r is the rate of interest and V is the value of forest land. Note that $px(t)e^{-rs} - w$ is the net present value benefit from one rotation. Each subsequent benefit is then discounted by one more rotation period. Using the theorem for infinite geometric series, we can write the value of forest land as $V = [px(s)e^{-rs} - w]/(1 - e^{-rs})$. Differentiating this with respect to the rotation length s gives the Faustmann optimal rotation equation:

$$px'(s) - rpx(s) - r[px(s)e^{-rs} - w]/(1 - e^{-rs}) = 0. \tag{4}$$

According to this view the stand is cut when the value of letting the stand grow an additional year, $px'(t)$, equals the combined interest costs on the first harvest, $rpx(t)$ and on the value of bare forest land, $r[px(s)e^{-rs} - w]/(1 - e^{-rs})$. It is possible to show that the longer the Faustmann rotation period is, the higher the planting costs and the lower the timber price and rate of interest (Johansson and Löfgren 1985, p. 82). For example, in southern Finland, the Faustmann rotation period is very sensitive to variations in the rate of discount but typically varies between 50 and 80 years.

The Faustmann model has a history of 150 years (see Johansson and Löfgren 1985; Samuelson 1976). The model was long unknown in economics and many famous economists have specified the rotation problem incorrectly. The most usual mistake has perhaps been to take into account only the first harvest instead of the infinite chain of rotations. This shortsighted view implies an excessively long rotation period and reflects the assumption that land is not a scare factor of production in forestry.

The Faustmann model specifies the value of bare forest land when the rotation period in Equation (3) equals its optimal length as determined implicitly by Equation (4). Note that a forest owner has only a finite lifetime. The infinite

horizon reflects either the possibility that forest owners have bequest motives or that they can sell the forest land in perfectly functioning land markets. The chain of transactions implies that each forest owner has implicit economic incentives to apply an infinite horizon in his harvesting decisions. Differentiating the value of bare forest land and taking into account that $\partial V/\partial s = 0$, since the land value is maximized, yields the results that the value of forest land depends positively on timber price but negatively on planting costs and the rate of interest.

Figure 1 shows a numerical example of how the value of bare land depends on the rate of interest. When $r > 0.036$ the land value is negative. This simply means that even the maximized land value or profit is negative and the replanting costs exceed the present value gross timber income, i.e. $px(s_f)e^{-\delta s_f} - w < 0$, where s_f is the Faustmann rotation. Besides the rate of discount, the cause of negative land value can be a low timber price, high planting costs, or low growing capacity of the forest land. With negative values for bare land, a profit-maximizing landowner does not replant a new stand after the harvesting. If natural regeneration is absent, this leads to the outcome called 'forest mining'.

The possibility that the model may 'recommend' forest mining has caused much discussion and confusion. It can be hypothesized that in Finland the

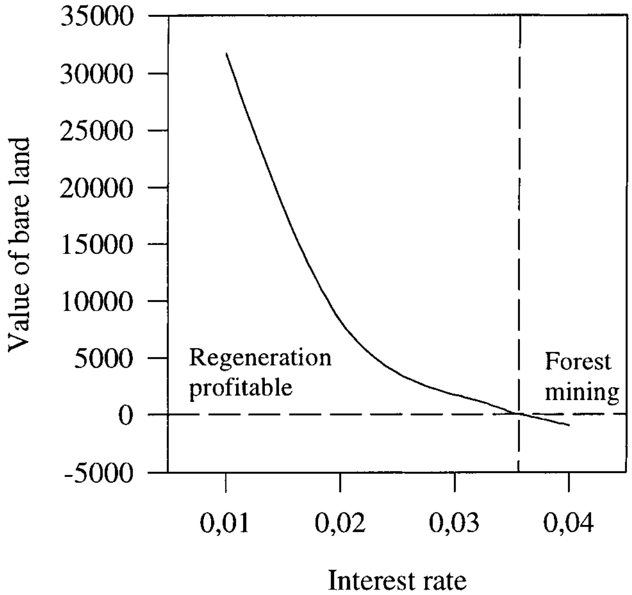

Figure 1. The value of bare land and 'forest mining'. Note: The figure is based on the numerical example: $x(s) = a - be^{-gs}$, $a = 600$, $b = 842.9$, $g = 0.012$, $p = 170$, $w = 4000$.

value of bare land is negative in large forest areas. There have been two different types of response to this. Finnish forest law requires that replanting must be done within five years after the harvest. Second, since the Faustmann model is widely used in determining the rotation period and land value, the model is 'modified' by decreasing the rate of discount below the levels suggested by the market rate of interest. In fact forestry experts apply different rates of interest in different parts of the country in order to prevent negative land values and to obtain the 'correct' rotation period (see e.g. Tapio 1998, p. 446). This approach is clearly implausible; any other model parameter could also be 'modified' from the correct values to get certain desired result.

As a reaction to the undesired implication of discounting, the ecology textbook by Begon et al. (1996, p. 666) suggest that a 'new economics' is needed that is able to treat values in a broader sense than merely prices of things that are bought and sold. This statement is understandable in the sense that, for example, the Faustmann model and similar models in fishery economics are in many cases too restrictive. However, in a broader context the statement may be unwarranted since it is based on a very limited view of the existing economics, which is not at all restricted to values directly realized in markets.

According to several studies, timber-harvesting decisions depend on forest owner-specific parameters like nonforest income, which are absent from the Faustmann model (e.g. Dennis 1990). Moreover, some recent studies suggest that the price paid for forest land may depend on buyer- and seller-specific characteristics that do not enter into the Faustmann land value formula (Aronsson and Carlén 1997). Thus the Faustmann model is problematic as an empirical description of how forest owners behave. As a normative rule, the Faustmann model is problematic since it assumes that the aim of the forest owner is profit maximization. Usually economic decision making is explained by applying some form of the theory of rational choice. In the case of individuals or consumers, this leads to maximization of lifetime welfare (Fisher 1930; Yaari 1964). Compared to this, the aim of profit maximization is highly restrictive. The Faustmann model also assumes that forests are valuable only because of timber, and all values related to biodiversity, recreation, scenery etc. are neglected.

As a response to these difficulties, forest economic research presently contains two different traditions (see Amager 1997). One tradition follows the Faustmann model and continues to rely on the profit maximization hypothesis. Within this tradition, Hartmann (1976), Strang (1983) and Clark (1990), for example, have extended the model to cover nonmarket or *in situ* values. The problem that remains is that these specifications are still based on profit maximization and cannot explain why forest harvesting decisions depend on forest owner-specific factors like nonforest income.

The two-period tradition has generalized the profit maximization assumption to utility maximization and contains numerous interesting studies that explain why forest harvesting decisions empirically depend on parameters not included in the Faustmann model. However, as noted, for example, by Johansson and Löfgren (1985, p. 8), the two-period specification does not describe the forest harvesting decision as a rotation problem. Instead, the forest is described as a homogeneous biomass which is harvested continuously as in the homogeneous biomass fishery models or surplus yield models (see Clark 1976 or Begon et al. 1996, p. 652). This simplification of forest biology greatly simplifies the mathematics of economic optimization. From the economic point of view it can be argued that even the most stylized specification of the forest biology may not change the most basic economic features of the decision problem. However, Berck (1976), Johansson and Löfgren (1985, p. 55) and Binkley (1987), for example, have argued that, since the homogeneous biomass approach neglects the fact that the growth of the forest depends on its age composition, the approach cannot describe some of the most essential features of forestry. For example, it cannot yield descriptions that explain which trees or stands should be harvested at a given moment of time. It is interesting to note that there is a very similar discussion going on regarding fisheries (see Beagon et al. 1996, p. 660). Because of these problems with the homogeneous biomass approach, we continue to study some recent models that generalize the forest rotation problem without excluding the biologically more accurate age class description of forests.

In situ values in a household consumption/savings model

Within the various disciplines studying forestry and natural resource utilization, there are many different views on how *in situ* or amenity values should be taken into account in decision making. Some foresters believe that it is the addition of non-material-benefit functions that brings value judgements into an otherwise value free-forestry model (e.g. Kuusela 1994, p. 122). Another view is represented by this journal, which calls for studies that consider social and economic constraints on conservation (see the cover). In contrast, one basic approach in economic models is to take into account the *in situ* values as constraints, implying that timber income may be maximized only within certain limits that guarantee the existence of some species, for example. Another possibility is to apply a formulation where the forest owner makes value comparisons between timber income and the *in situ* value of his forest.

At the macro level this last approach is also noted by Begon et al. (1996, p. 917) who write:"To be effective, it may be that the arguments of conservationists must ultimately be framed in cost-benefit terms because governments

will always determine their policies against a background of the money they have to spend and (sometimes) the priorities accepted by their electorates.'' In a recent study (Pouta et al. 1998), about 2000 Finnish citizens were asked whether they generally agree with the statement that in nature conservation decision making it is always important to balance the conservation costs and benefits. About 77% of the respondents strongly agreed or agreed with this statement.

The view taken here, which is consistent with environmental and natural resource economics, is that the choice between these different approaches is ethical. In economics such choices should essentially be made by citizens rather than researchers. During the last 30 years environmental economists have developed empirical methods for studying citizens' environmental preferences (see e.g. Johansson 1993). At the most general level this work suggests (e.g. Pouta et al. 1998) that perhaps the majority of people accept value comparisons between environmental quality and the level of their income, for example. There is no doubt that this view contradicts a common conservationist ethic that environmental values cannot be commensurable with related monetary values. However, empirical research in environmental economics shows that assuming commensurability between environmental values and level of income, for example, is one serious approach on which to base decision-making models. This holds especially for descriptive theories. In addition, it is next shown that one form of commensurability and incommensurability can be simultaneously included within the theory of rational choice, which is a cornerstone of modern economics.

Following the theory of rational choice (see e.g. Harsanyi 1976), we state that if the decision maker is willing to choose alternative A instead of alternative B, his utility is higher if he obtains alternative A instead of B, whatever the reasons behind this preference. In Figure 2, the vertical axis measures the characteristics of the forest (e.g. the stand age) that are relevant in terms of *in situ* values. The horizontal axis measures the level of timber income. An indifference curve specifies those combinations of income and state of the forest between which the owner is indifferent. Indifference curves further from the origin yield higher utility. If we move along a single indifference curve from left to the right we note that to be equally well off the forest owner requires an increasing amount of timber income as compensation for the deteriorating *in situ* characteristics of his forest. The preferences may well take such a form that no increase in timber income can compensate the loss in the state of the forest if the latter falls below level a in Figure 2. A similar situation may hold for the level of timber income. Thus within this approach it is possible to take into account that the forest owner may not be willing to make value comparisons that decrease the *in situ* characteristics of his forest (or the rate of consumption) at too low a level.

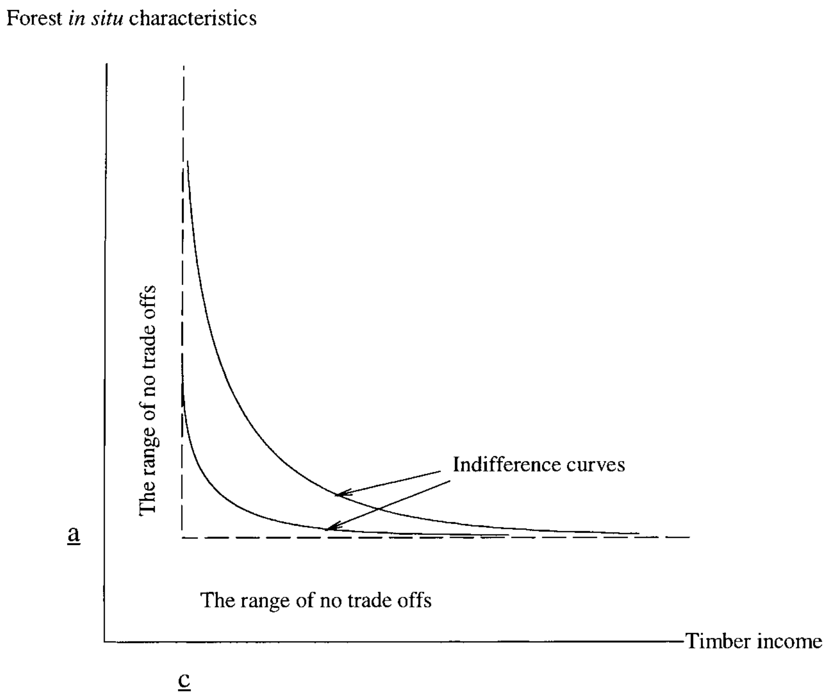

Figure 2. Value comparisons between timber income and *in situ* characteristics of forests.

A forestry model that includes *in situ* preferences in line with the theory of rational choice is as follows (Tahvonen 1997; Tahvonen and Salo 1999):

$$\max_{\{t_i, c\}} W = \int_0^{\infty} [U(c) + A(s)]e^{-\delta t} \, \mathrm{d}t \tag{5}$$

subject to

$$\dot{a} = ra - c + m, \quad \text{when } t \neq t_i \tag{6}$$

$$\dot{x} = F(x), \quad \text{when } t \neq t_i, \tag{7}$$

$$a(t_i) = a(t_i^-) + px(t_i^- - t_{i-1}) - w, \tag{8}$$

$$x(t_i) = x_0, \quad a(0) = a_0, \quad x(0) = x_0, \quad \lim_{t \to \infty} a(t) \geq 0. \tag{9}$$

Specification (5)–(9) is a decision-making problem where the aim of the household forest owner is to maximize welfare or utility by choosing a consumption time path c and a forest harvesting schedule in terms of optimal cutting moments, t_i. Equation (5) defines the forest owner's preferences. At any moment of time t his utility from consumption is $U(c)$, where $c(t)$ is the rate of consumption (in monetary terms) and $U' > 0$, $U'' < 0$. As in Clark (1990), the *in situ* value of the forest is measured by its age, denoted by s. We assume that

the *in situ* value A increases with stand age but at a decreasing rate, i.e. $A'' \geq 0$. It may well be possible that the dependence of *in situ* value on stand age is different from that assumed here. Numerous other possibilities can be studied within this model.

The terms $U(c) + A(s)$ specify the forest owner's instantaneous utility as a function of consumption and the age of his forest (cf. Figure 2). The instantaneous utility is integrated oven an infinitely long time horizon. This reflects bequest motives of the forest owner and all his successors. These bequest motives imply that each forest owner generation makes decisions as if it lived forever. Again this is only one possibility to specify the model. In Tahvonen (1997), it is shown how different kinds of bequest motives can be included in the model. The discounting term $e^{-\delta t}$ reflects the forest owner's subjective rate of time preference, and we can include the possibility that $\delta = 0$, i.e. that the forest owner does not discount his future utility. Equations (6)–(9) specify the optimization constraints. Equation (6) shows the dynamics of the forest owner's savings, and variable a denotes financial assets, r the rate of interest and m the level of nonforest income. In Equation (7) the (annual) growth of an even aged stand is $F(x)$, where $x(s)$ is the level of (commercial) cubic meters. Equation (8) shows the level of savings immediately after the stand is harvested. Savings is equal to the level just before the harvesting moment, $a(t_i^-)$, plus the net timber income, $px(t_i^- - t_{i-1}) - w$. Note that t_i is the harvesting moment i and $t_i^- - t_{i-1}$ ($\equiv s_i$) is thus the age of the harvested stand. The constraints (7) and (8) together imply that in this model the forest owner is looking for the correct moment to harvest and sell his stand, just as in the Faustmann model. The constraints in Equation (9) are the initial and terminal values of the stand volumes and savings. The specification (5)–(9) is a model that contains one even aged stand as the Faustmann model. In Tahvonen (1997) and Tahvonen and Salo (1997) it is shown that the model can be generalized to contain any number of even aged stands (or trees).

The model (5)–(9) can be solved using the methods of dynamic optimization described, e.g. in Clark (1990). At the most general level the outcome of the model depends critically on whether the forest owner is a saver or is consuming his savings (i.e. whether $r \gtreqless \delta$). In the case of low subjective time preference, financial assets accumulate and the rational forest owner increases his consumption level and additional units of consumption became less and less important over time. This implies that also the timber income becomes less important and the owner is willing to lengthen the rotation in order to increase the level of *in situ* utility obtained during each rotation. Finally this leads to an infinitely long rotation, i.e. when the owner (or his successor) is wealthy enough, the stand is left uncut and consumption is based solely on nonforest income and interest on savings. In contrast, if the forest owner is consuming his

savings, the rotation period becomes shorter harvest after harvest and will approach the Faustmann rotation over time (Tahvonen and Salo 1997). These properties are a major complication with respect to the classical Faustmann model, where the rotation period is always constant.

We obtain a special case of this model when the rate of interest equals the subjective rate of time preference, i.e. $\delta = r$. In this case the optimal consumption time path is constant over time. The optimal harvesting solution may now be a constant rotation period that is repeated forever as in the Faustmann model. The other possibilities are that the owner harvests the forest only a finite number of times and then gives up harvesting or that it is optimal to abandon harvesting immediately. These latter types of solutions occur when the *in situ* values are high enough relative to consumption preferences. We next study more closely the basic case of the model where $\delta = r$ and where harvesting continues forever.

Denote the constant consumption level by c_0. Over the infinite horizon the forest owner and his successors cannot consume more than the sum of their earnings and initial savings:

$$a_0 + \int_0^\infty m e^{-\delta t}\,\mathrm{d}t + \sum_{i=1}^{\infty}[px(s)e^{-\delta s} - w]e^{-\delta s i} - \int_0^\infty e^{-\delta t} c_0 \geq 0. \tag{10}$$

Because $\int_0^\infty c_0 e^{-\delta t}\mathrm{d}t = c_0/\delta$, we can solve c_0 from Equation (10) since it cannot be optimal to leave any financial resources unused:

$$c_0 = m + \delta a_0 + \delta[px(s)e^{-\delta s} - w]/(1 - e^{-\delta s}), \tag{11}$$

where we used the theorem of infinite geometric series. Thus the level of consumption equals simply nonforest income plus the interest on savings and interest on the timber value of forest land. Next we can write the forest owner's problem for determining the optimal rotation length as

$$\max_{\{s\}} W = U(c_0)/\delta + \sum_{i=1}^{\infty} e^{-\delta s i}\int_0^s A(\sigma)e^{-\delta\sigma}\,\mathrm{d}\sigma, \tag{12}$$

where σ is a constant of integration. Note that due to the assumption $\delta = r$ it is possible to give the optimization problem by Equations (11) and (12) instead of the more general case defined by Equations (5)–(9).

To carry out the maximization in Equation (12), set the derivative of W with respect to the rotation length equal to zero. This leads to

$$\begin{aligned} &U'(c_0)\{px'(s) - \delta px(s) - \delta[px(s)e^{-\delta s} - w]/(1 - e^{-\delta s})\} + A(s) \\ &- \delta\int_0^s A(\sigma)e^{-\delta\sigma}\,\mathrm{d}\sigma/(1 - e^{-\delta s}) = 0. \end{aligned} \tag{13}$$

This equation can be compared with the Faustmann Equation (4). If we neglect *in situ* values and $A(s) \equiv 0$, our model gives the same rotation length as the Faustmann model since $U'(c_0) \neq 0$. Because $A(s) - \delta \int_0^s A(\sigma) e^{-\delta\sigma} d\sigma / (1 - e^{-\delta s}) > 0$ and $U'(c_0) > 0$, it follows that the Faustmann term in the equation must be negative, implying that the optimal rotation period with *in situ* benefits must be longer than the Faustmann rotation. Note that the rotation period is optimal when the marginal utility from consumption, $U'(c_0)\{\cdot\}$, equals the marginal *in situ* utility of the forest, $A(s) - \delta \int_0^s A(\sigma) e^{-\delta\sigma} d\sigma / (1 - e^{-\delta s})$, i.e. the forest owner cannot increase his welfare by making changes in his forest management decisions.

Compared to the Faustmann model, the important difference between Equations (13) and (4) is that the rotation period defined implicitly by Equation (13) depends on the forest owner-specific characteristics such as his initial savings, nonforest income, and preferences related to discounting, consumption and *in situ* valuation. In contrast, the Faustmann rotation period depends only on general and observable facts like the price of timber or market rate of interest. Thus within our model no outside observer or forestry adviser can give instructions on the economically optimal rotation period without knowing the detailed forest owner-specific characteristics. This is in sharp contrast with historical forestry practices in Finland, for example. We also note that *in situ* preferences restrict the set of cases where "forest mining" is optimal. However, the optimality of this solution depends fundamentally on the decision-maker's preferences, and empirically relevant descriptive models should include this possibility.

Using Equation (13) it is possible to study analytically how the harvesting decision depends on model parameters. We will however study this question by the numerical examples in Figure 3. The growth function used in the numerical computation approximates one hectare *Pinus silvestris* stand in souther Finland. In Figure 3a, the rotation period becomes longer as the parameter describing *in situ* preferences increases. Without *in situ* values, the rotation period equals the Faustmann rotation. Note that if we interpret the MSY concept using the commercial biomass $x(s)$, it follows that the MSY rotation is always shorter than the rotation according to the 'Forest Rent' approach. It is quite possible that the rotation period defined by Equation (13) is the longest of the four alternatives.

Figure 3b shows the present value of timber income related to different rotation periods. By definition, the Faustmann model yields the highest level of timber income. In Finland the MSY and Forest Rent approaches easily lead to negative present value timber income (net of planting costs). This is the case also in our model if the *in situ* valuation leads to long rotation periods.

In Figure 3c the rotation period defined by Equation (13) increases with nonforest income. Intuitively this follows because with higher nonforest in-

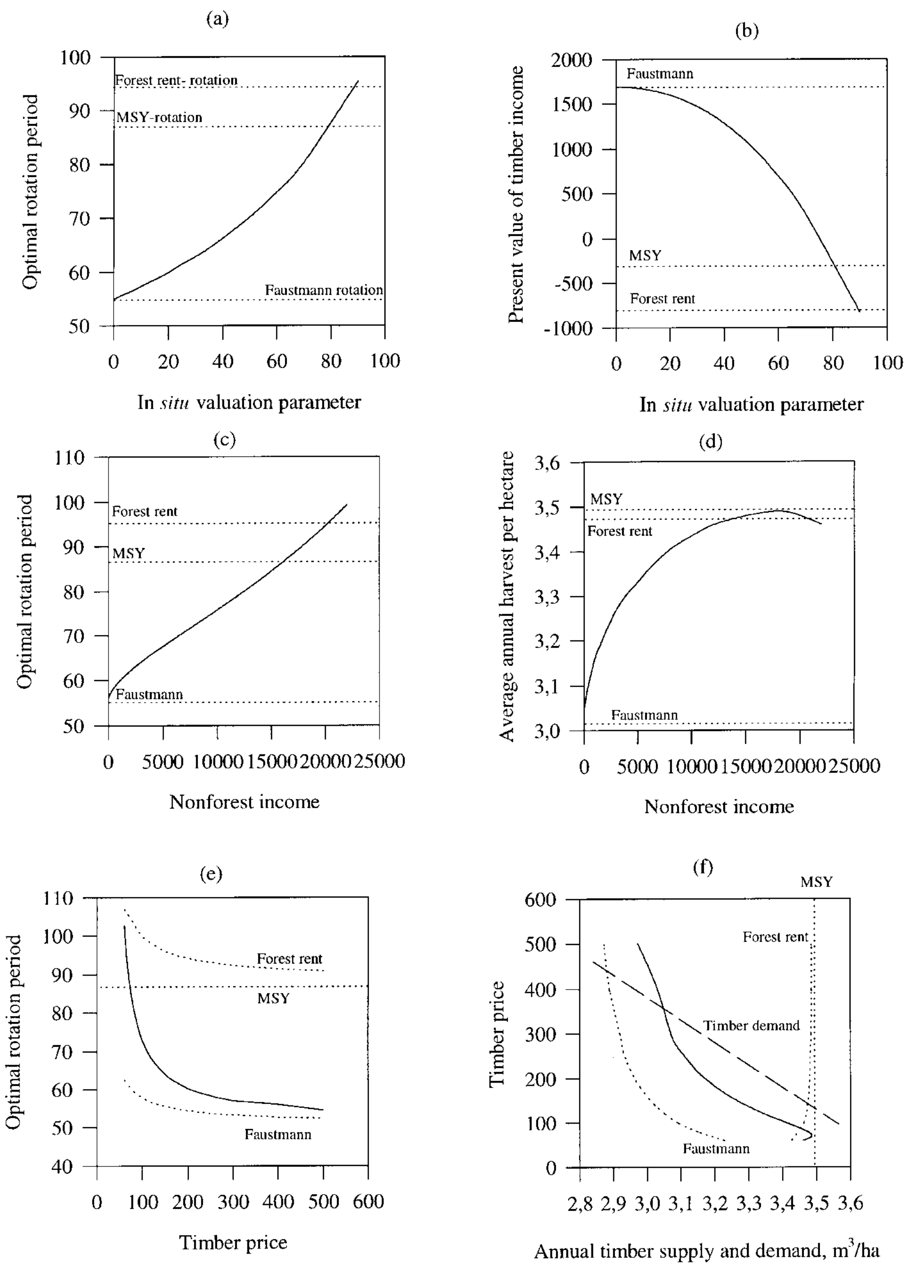

Figure 3. The dependence of forest harvesting decisions on model parameters. Note: The figure is based on the example: $U(c) = (c^{1-\alpha}/(1-\alpha)$, $x(s) = a - be^{-gs}$, $A(s) = \tau(1 - e^{-ks})$, $a = 600$, $b = 842.9$, $g = 0.012$, $k = 0.01$, $a_0 = 1000$, $p = 170$, $m = 1000$, $w = 4000$, $\alpha = 0.5$, $\delta = 0.03$, $\tau = 20$.

come additional increases in consumption become less important and the forest owner may increase his welfare by decreasing the level of timber income in order to increase the *in situ* value of his forests. Figure 3d shows the average annual harvest per hectare. By definition, this is maximized by the MSY rotation. Note that *in situ* valuation may well increase the average annual harvest per hectare from the Faustmann level. This is in contrast with the typical concern that *in situ* valuation reduces physical timber production.

Increases in timber price always reduce rotation length in the Faustmann and Forest Rent approaches (Figure 3e). In general, the rotation period defined by Equation (13) may increase or decrease with the price level. Figure 3f shows timber supply functions and a hypothetical demand curve in the case of a normal forest that contains all stand age classes between zero and the rotation age. Note that in the case depicted the Faustmann model leads to the highest timber price and lowest quantities bought and sold. At the other extreme are the MSY and Forest Rent rotations, which lead to the lowest price and highest quantities. The market equilibrium defined by Equation (13) is typically between these extreme cases.

Economic models of the forest owner's harvesting decisions can be tested empirically by either studying the timber harvesting decisions or the determination of the price of forest land. A major problem with the Faustmann model is that it cannot explain the empirical dependence of forest harvesting and timber supply decisions on the forest owner's nonforest income (Binkley 1981). Our model predicts that the average annual harvest per hectare will be higher for forest owners with higher income, given that the rotation period is shorter than the MSY rotation. Recently, this hypothesis has received empirical support using data from southern Finland (Kuuluvainen and Tahvonen 1987).

On the value of forest land

To study our model predictions concerning forest land prices we define the reservation price as the lowest price at which the forest owner is willing to sell the forest without being worse off than as a forest owner. Thus the reservation price V_1 is defined by

$$U[\delta(a_0 + V_1) + m]/\delta - U(c_0)/\delta - \sum_{i=1}^{\infty} e^{-\delta si} \int_0^s A(\sigma)e^{-\delta\sigma}\,\mathrm{d}\sigma = 0, \tag{14}$$

where $U[\delta(a_0 + V_1) + m]/\delta$ is the present value welfare level after the forest is sold at price V_1. Note that this specification describes a case of a private property regime where the forest owner obtains *in situ* benefits from his forest only if the forest is in his possession. By differentiating Equation (14) it is

possible to show that the reservation price increases with the forest owner's income level. Among other things, this implies that with equal consumption and time preferences, the buyer of forest land must either have a higher *in situ* valuation or a higher income level than the present owner before a transaction between rational forest owners is possible. These hypothesis have received support from an empirical study of Swedish forest land prices, in which the seller's income has a positive and significant effect on price (Aronson and Carlén 1997). Note that the Faustmann hypothesis on land prices is given by Equation (3), where the land price is independent of any forest owner characteristics.

In various nature conservation programs (see e.g. Hildén et al. 1998), environmental officials buy private forest land for conservation purposes or pay compensations to forest owners for not harvesting their forests. In Finland, such compensations is paid using practical procedures that approximate the Faustmann land value formula. We can study this question using Equation (14). It directly suggests that the Faustmann land value cannot constitute sufficient compensation if a forest is bought from an owner with *in situ* preferences. This follows because the forest owner could apply the Faustmann rotation period and thus obtain the Faustmann timber income but prefers to apply the longer rotation defined by Equation (13). However, this reasoning assumes that the forest owner obtains *in situ* utility only if the forest is in his possession. Another possibility is that the forest owner has such preferences that only the timber income is lost if the forest is sold for environmental preservation purposes. In these cases the forest owner's reservation price V_2 is defined by

$$U[\delta(a_0 + V_2) + m]/\delta + \int_0^\infty A(\sigma)e^{-\delta\sigma}\,\mathrm{d}\sigma - U(c_0)/\delta - \sum_{i=1}^{\infty} e^{-\delta s i}\int_0^s A(\sigma)e^{-\delta\sigma}\,\mathrm{d}\sigma = 0. \tag{15}$$

Since, after selling the forest, the *in situ* value is determined by infinite rotation, it follows now that V_2 must be lower than the timber income the forest owner obtains when the forest is in his possession. Thus V_2 must also be below the Faustmann land value. By differentiating Equation (15) it is possible to show that V_2 is the lower, the higher the forest owner's income level. This follows because with higher nonforest income the owner applies a longer rotation and thus requires less compensation to cover a lower level of lost timber income. Thus our model suggests that conservation programs (with budget constraints) should not be based on land purchases from those forest owners whose *in situ* valuations depend on the ownership of land. A more cost-efficient policy is to find those owners that have high *in situ* valuation and high nonforest income

and that require compensation only for lost timber income. In principle, these owners could be found by applying a competitive bidding procedure. Such a procedure might lead to major cost savings but is, for example, in Finland ruled out by the law (Hildén et al. 1998).

Conclusions

Understanding the economic aspects of forest harvesting decisions of household forest owners is important in countries like Finland and Sweden where households own a major part of the forest land. Most simple (and historically most influential) views on harvesting decisions assume that the aim of forest owners is to maximize physical output or that the market rate of interest is zero. The classical economic approach, i.e. the Faustmann model, is applied in forestry practices in many countries. In this model the aim is profit maximization, and the model neglects *in situ* values of forests. We develop a model that generalizes this approach and shows how the optimal rotation period depends on forest owner-specific characteristics. Various implications of this model differ sharply from the classical economic model. The model can be extended to include multiple stands, forest thinning, or imperfect capital markets, so that it can more accurately describe the various problems of household forest owners, timber markets and nature conservation programs.

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